



US009217847B2

(12) **United States Patent**
Lee et al.

(10) **Patent No.:** **US 9,217,847 B2**
(45) **Date of Patent:** **Dec. 22, 2015**

(54) **IMAGING LENS**

(71) Applicant: **GENIUS ELECTRONIC OPTICAL CO., LTD.**, Taichung (TW)

(72) Inventors: **Poche Lee**, Taichung (TW); **Kuo-Wen Chang**, Taichung (TW); **Long-Sheng Liao**, Taichung (TW)

(73) Assignee: **GENIUS ELECTRONIC OPTICAL CO., LTD.**, Taichung (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/720,648**

(22) Filed: **May 22, 2015**

(65) **Prior Publication Data**

US 2015/0253549 A1 Sep. 10, 2015

Related U.S. Application Data

(60) Continuation of application No. 14/621,251, filed on Feb. 12, 2015, which is a continuation of application No. 14/493,024, filed on Sep. 22, 2014, now Pat. No. 8,988,795, which is a division of application No. 14/303,080, filed on Jun. 12, 2014, now Pat. No. 8,922,915, which is a continuation of application No. 13/013,164, filed on Jan. 25, 2011, now Pat. No. 8,792,187.

(30) **Foreign Application Priority Data**

Sep. 10, 2010 (TW) 99130640 A

(51) **Int. Cl.**

G02B 13/00 (2006.01)

G02B 9/34 (2006.01)

(52) **U.S. Cl.**

CPC **G02B 13/004** (2013.01); **G02B 9/34** (2013.01)

(58) **Field of Classification Search**

CPC .. G02B 13/004; G02B 13/002; G02B 13/001; G02B 9/34

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,792,187 B2 * 7/2014 Lee G02B 13/004 359/715
8,922,915 B2 * 12/2014 Lee G02B 13/004 359/715
8,937,775 B2 * 1/2015 Lee G02B 13/004 359/715
8,988,795 B2 * 3/2015 Lee G02B 13/004 359/715

* cited by examiner

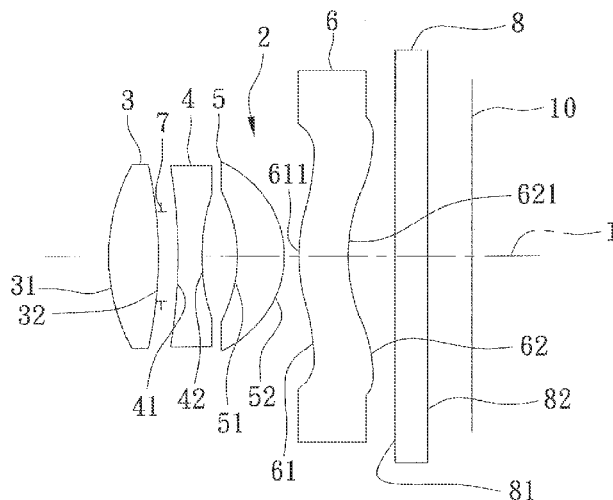
Primary Examiner — David N Spector

(74) *Attorney, Agent, or Firm* — Kilpatrick Townsend and Stockton LLP

(57) **ABSTRACT**

An optical imaging lens includes a plurality of lens elements having a refracting power, an object-side surface facing toward the object-side, and an imaging-side surface facing toward the imaging-side. The plurality of lens elements include a first lens element closest to the object-side, a second lens element second closest to the object-side, and a third lens element third closest to the object-side. The plurality of lens elements also include a fourth lens element closest to the imaging-side.

14 Claims, 7 Drawing Sheets



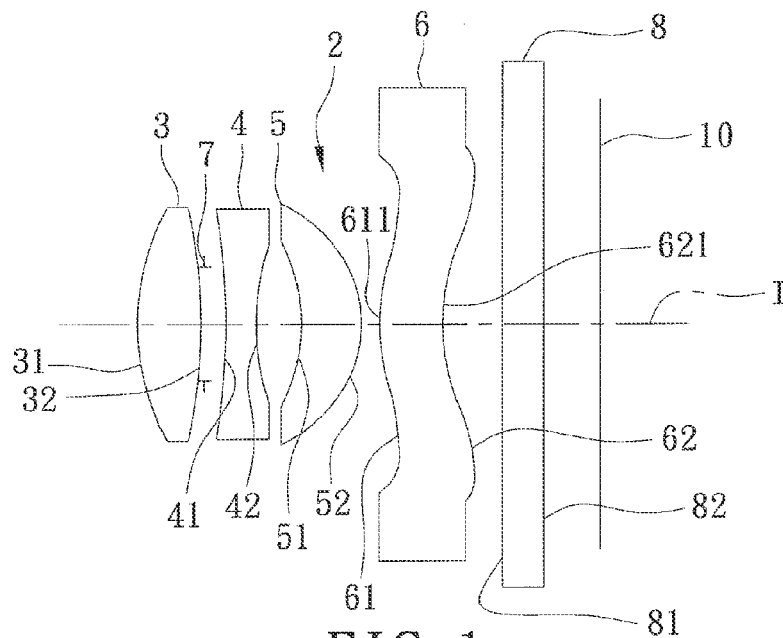


FIG. 1

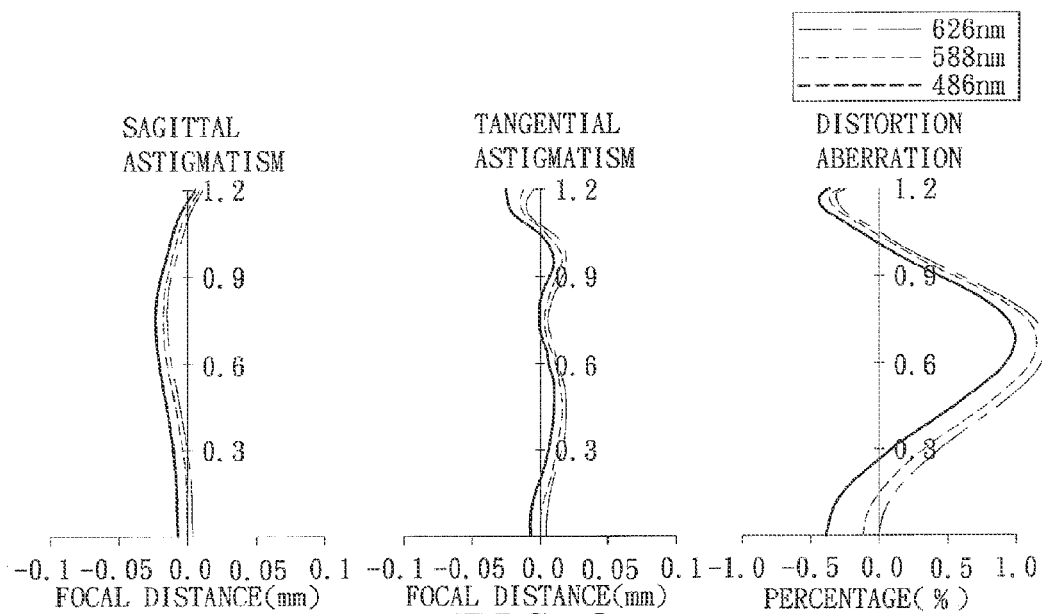


FIG. 2

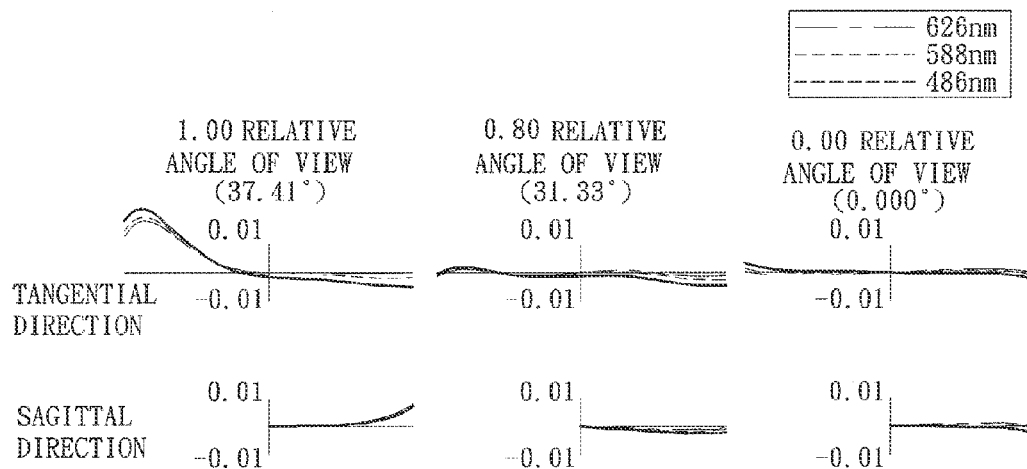


FIG. 3

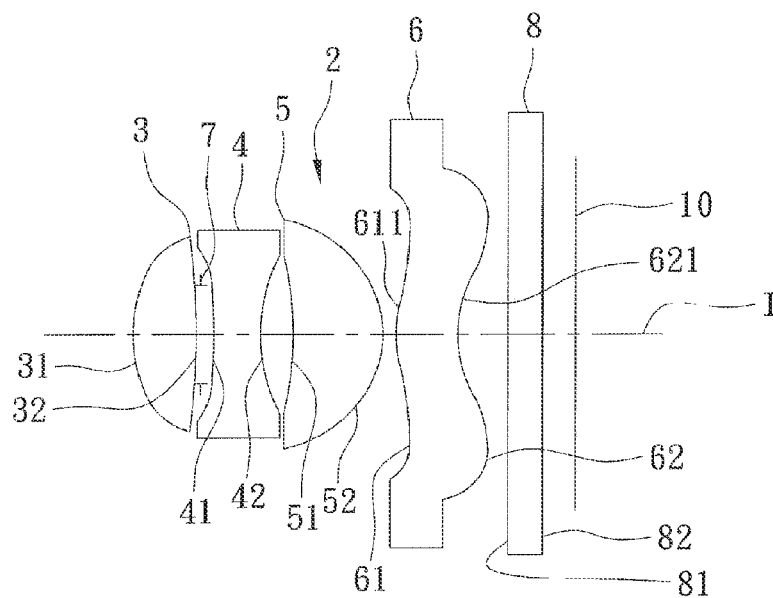


FIG. 4

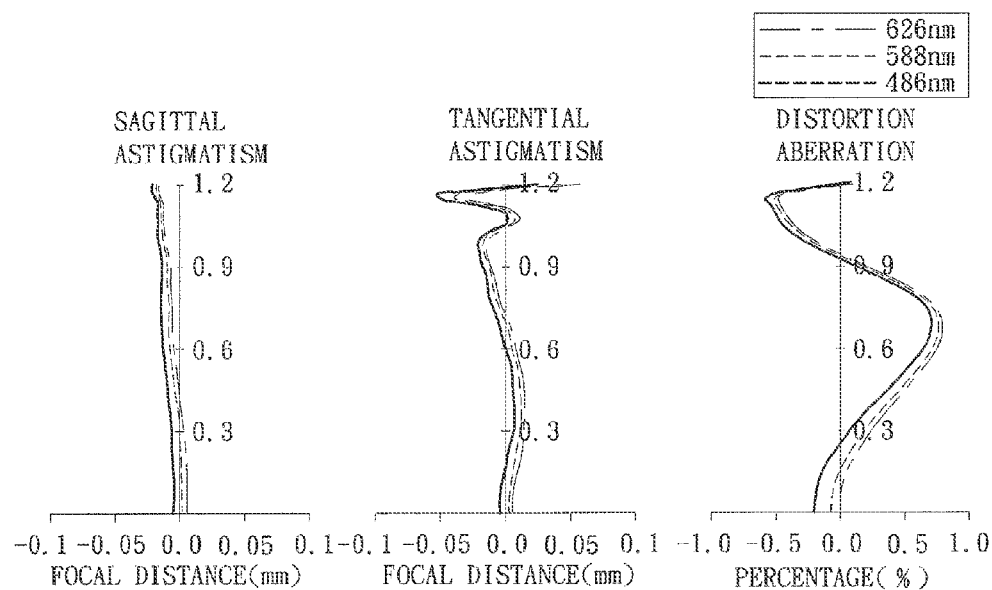


FIG. 5

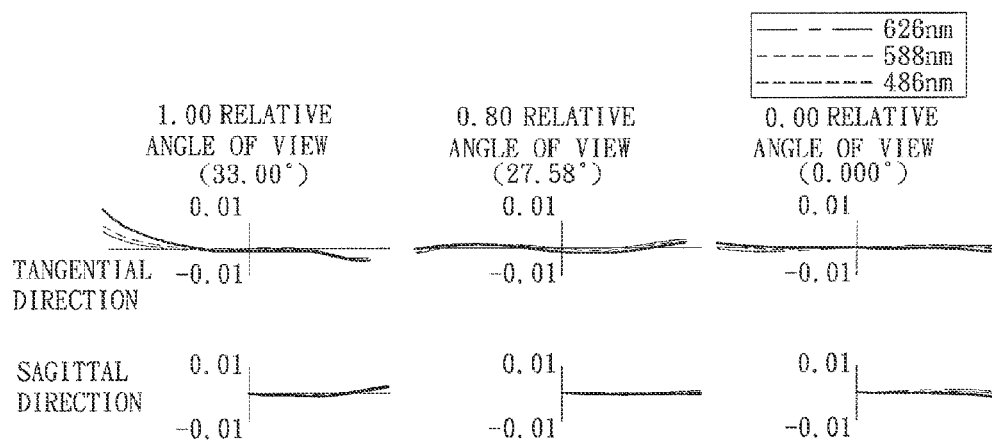


FIG. 6

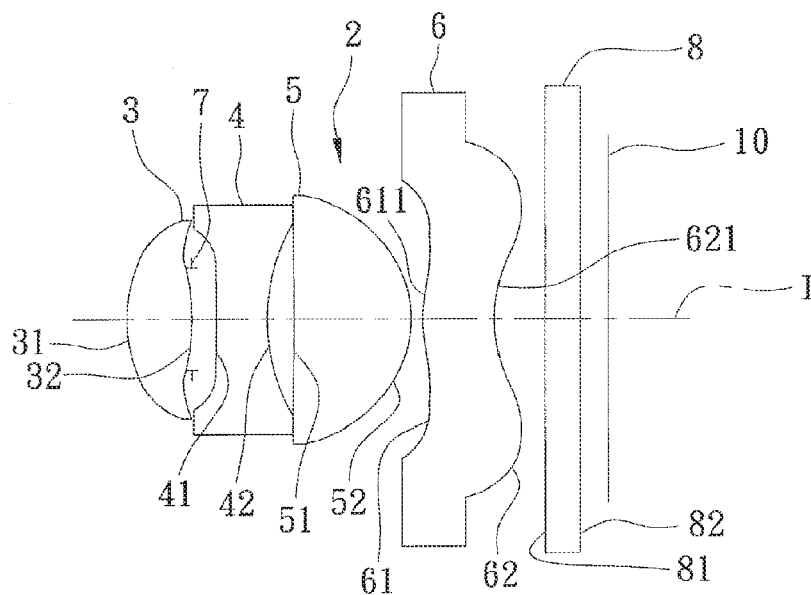


FIG. 7

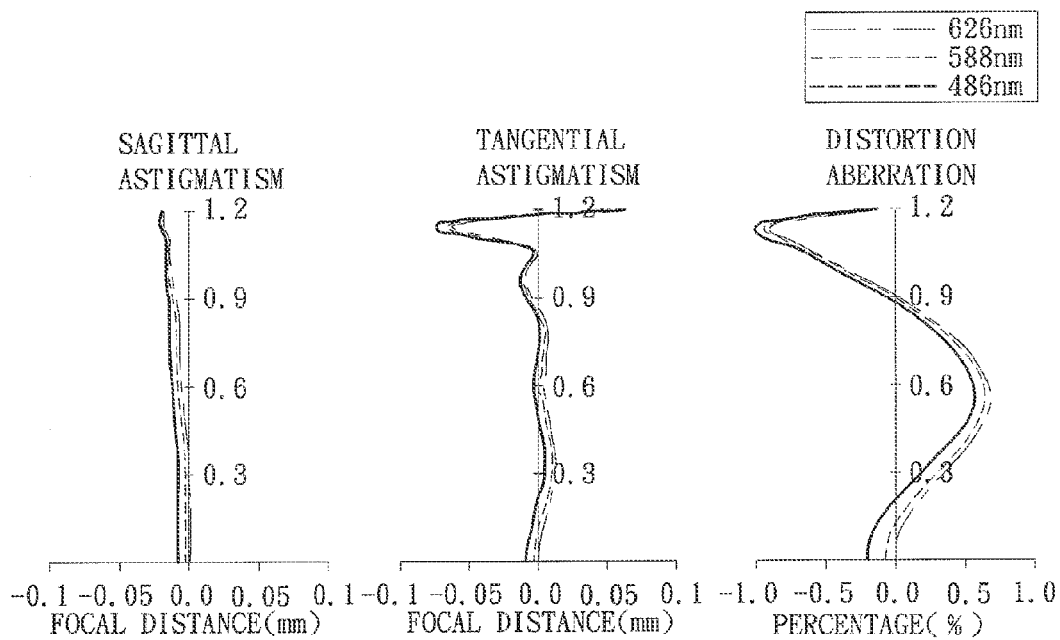


FIG. 8

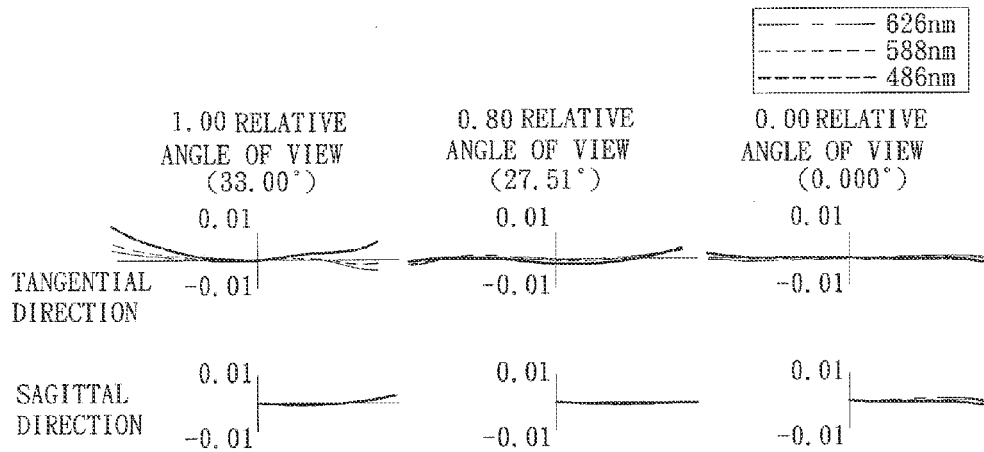


FIG. 9

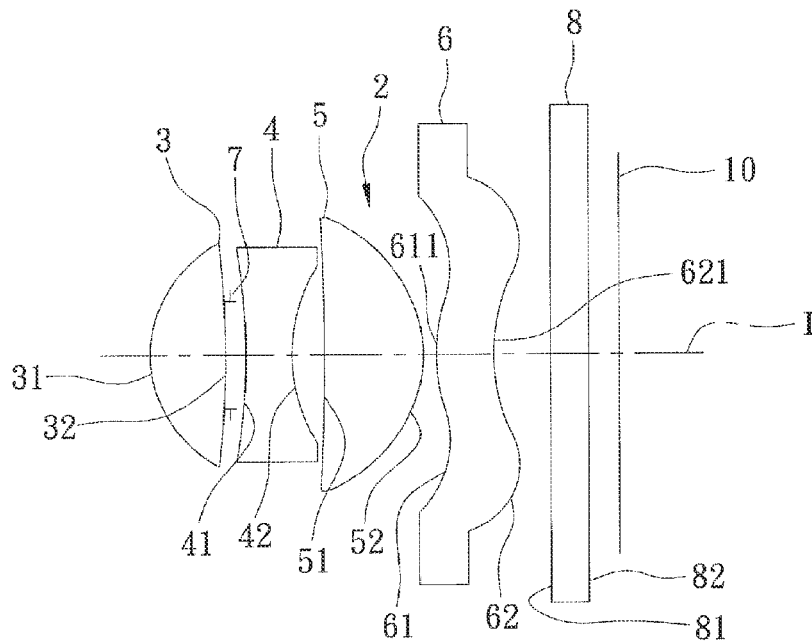


FIG. 10

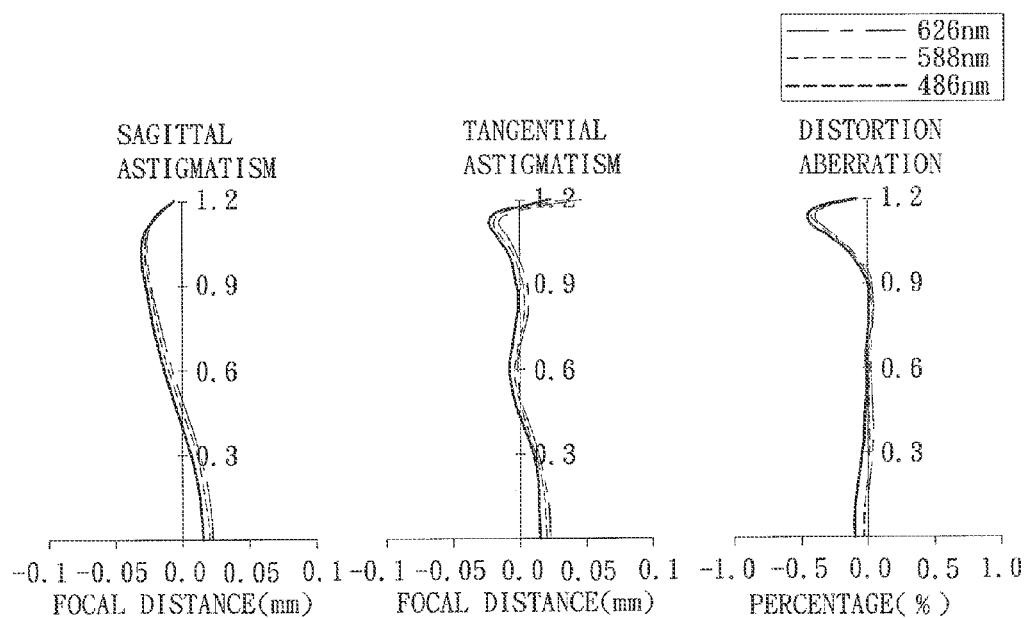


FIG. 11

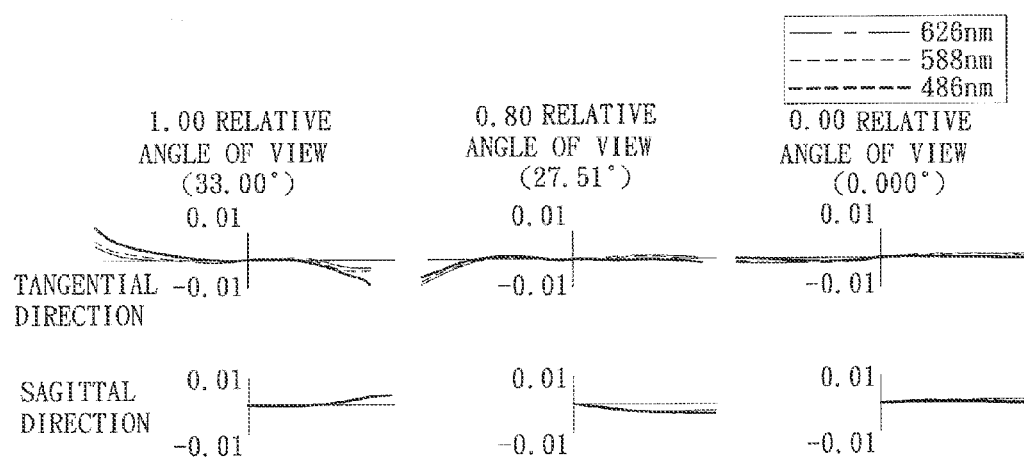


FIG. 12

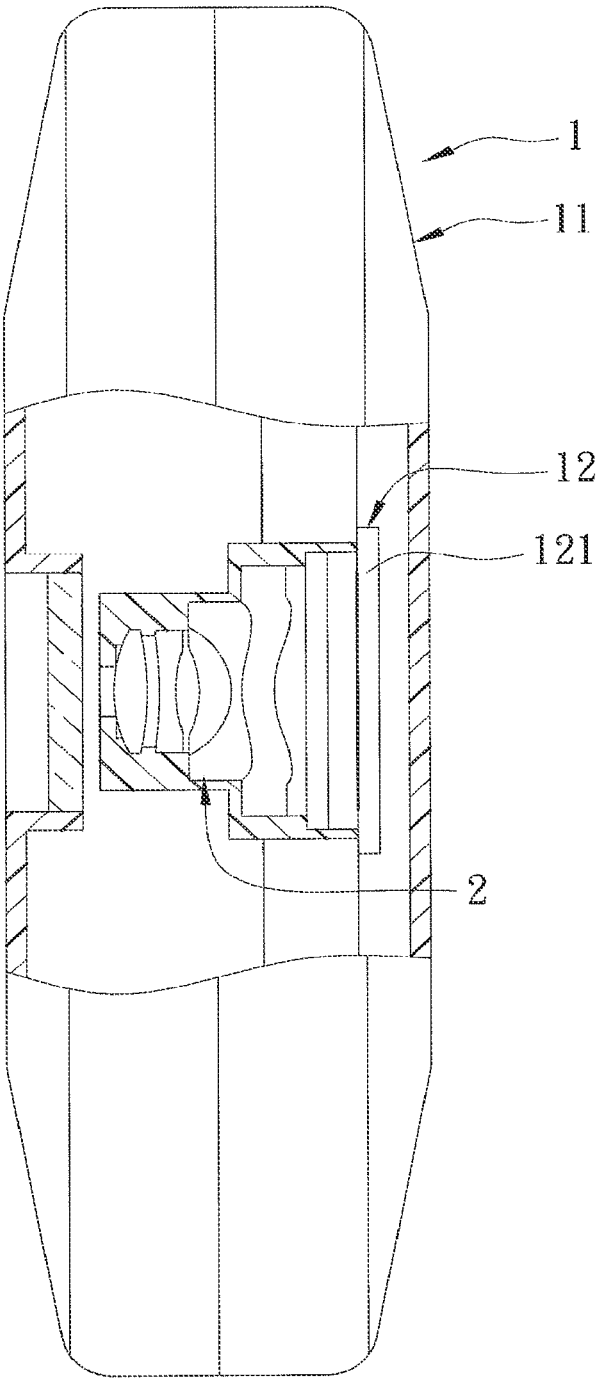


FIG. 13

IMAGING LENS

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/621,251, filed Feb. 12, 2015, which is a continuation of U.S. patent application Ser. No. 14/493,024, filed Sep. 22, 2014, now U.S. Pat. No. 8,988,795, which is a division of U.S. patent application Ser. No. 14/303,080, filed Jun. 12, 2014, now U.S. Pat. No. 8,922,915, which is a continuation of U.S. patent application Ser. No. 13/013,164, filed Jan. 25, 2011, now U.S. Pat. No. 8,792,187, which claims priority to Taiwanese Application No. 099130640, filed Sep. 10, 2010, the disclosures of which are hereby incorporated by reference in their entirety for all purposes.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an imaging lens and an electronic apparatus having the same, more particularly to an imaging lens with four lens elements and to an electronic apparatus having the same.

2. Description of the Related Art

In recent years, various electronic devices are designed to include imaging lenses and image sensors for image-capturing and video-recording capabilities. To improve portability and imaging performances while reducing dimensions and weights of the electronic devices, different combinations of lenses are installed in the electronic devices.

U.S. Pat. No. 7,453,654 discloses an imaging lens with four lens elements of different optical characteristics, one of which is a spherical glass lens element while remaining three of which are plastic aspherical lens elements for enhancing image quality. However, the spherical glass lens element is difficult to fabricate due to its small dimensions and radius of curvature, and therefore has drawbacks such as high costs and weight.

Besides, although the spherical glass lens element is able to achieve a relatively high positive refracting power at a relatively small radius of curvature such that an overall length of the imaging lens may be significantly reduced, the spherical glass lens element is known to exhibit high chromatic aberration due to its low Abbe number.

U.S. Pat. No. 6,476,982 discloses an imaging lens with first and second lens elements thereof adhesively bonded to each other to thereby reduce chromatic aberration. Nevertheless, such an approach to reduce chromatic aberration requires a strong bonding between the first and second lens elements, which is often difficult to achieve especially if the first and second lens elements are made of different materials, e.g., glass and plastic, respectively. While the first and second lens elements may both be made of glass, costs and weight of the imaging lens will, as a result, be compromised.

U.S. Pat. No. 7,466,497 discloses an imaging lens with four plastic lens elements. Although the imaging lens has a relatively short overall focal length and maybe fabricated at a relatively low cost, the imaging lens is known to exhibit high chromatic aberration.

Therefore, the need for a low cost, low weight imaging lens that exhibits low chromatic aberration still exists in the market.

SUMMARY OF THE INVENTION

Therefore, an object of the present invention is to provide an imaging lens capable of alleviating the drawbacks of the aforesaid imaging lenses of the prior art.

Accordingly, an imaging lens of the present invention includes first, second, third, and fourth lens elements arranged in the given order from an object side to an imaging side.

The first lens element is made of plastic, has a positive focusing power, and is biconvex. The second lens element is made of plastic, has a negative focusing power, is biconcave, and has an abbe number not greater than 30. The third lens element is made of plastic, has a positive focusing power, and has a convex imaging-side surface facing toward the imaging side. The fourth lens element is made of plastic, and has an imaging-side surface facing toward the imaging side and formed with a concave area in a vicinity of an optical axis of the fourth lens element. The imaging lens further includes an aperture stop disposed between the first and second lens elements.

Another object of the present invention is to provide an electronic apparatus having an imaging module.

Accordingly, an electronic apparatus of the present invention includes a housing and an imaging module that is disposed in the housing. The imaging module includes an imaging lens having an object side and an imaging side, and an image sensor disposed at the imaging side.

The imaging lens includes first, second, third, and fourth lens elements arranged in the given order from the object side to the imaging side. The first lens element is made of plastic, has a positive focusing power, and is biconvex. The second lens element is made of plastic, has a negative focusing power, is biconcave, and has an abbe number not greater than 30. The third lens element is made of plastic, has a positive focusing power, and has a convex imaging-side surface facing toward the imaging side. The fourth lens element is made of plastic, and has an imaging-side surface facing toward the imaging side and formed with a concave area in a vicinity of an optical axis of the fourth lens element. The imaging lens further includes an aperture stop disposed between the first and second lens elements.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the present invention will become apparent in the following detailed description of the preferred embodiments with reference to the accompanying drawings, of which:

FIG. 1 is a schematic diagram illustrating the first preferred embodiment of an imaging lens according to the present invention;

FIG. 2 illustrates plots of sagittal astigmatism, tangential astigmatism, and distortion aberrations of the imaging lens of the first preferred embodiment;

FIG. 3 illustrates ray fan plots of the imaging lens of the first preferred embodiment at different angles of view;

FIG. 4 is a schematic diagram illustrating the second preferred embodiment of an imaging lens according to the present invention;

FIG. 5 illustrates plots of sagittal astigmatism, tangential astigmatism, and distortion aberrations of the imaging lens of the second preferred embodiment;

FIG. 6 illustrates ray fan plots of the imaging lens of the second preferred embodiment at different angles of view;

FIG. 7 is a schematic diagram illustrating the third preferred embodiment of an imaging lens according to the present invention;

FIG. 8 illustrates plots of sagittal astigmatism, tangential astigmatism, and distortion aberrations of the imaging lens of the third preferred embodiment;

3

FIG. 9 illustrates ray fan plots of the imaging lens of the third preferred embodiment at different angles of view;

FIG. 10 is a schematic diagram illustrating the fourth preferred embodiment of an imaging lens according to the present invention;

FIG. 11 illustrates plots of sagittal astigmatism, tangential astigmatism, and distortion aberrations of the imaging lens of the fourth preferred embodiment;

FIG. 12 illustrates ray fan plots of the imaging lens of the fourth preferred embodiment at different angles of view; and

FIG. 13 is a schematic partly sectional view illustrating the preferred embodiment of an electronic apparatus, which includes a housing and an imaging module, according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Before the present invention is described in greater detail, it should be noted that like elements are denoted by the same reference numerals throughout the disclosure.

Referring to FIG. 1, the first preferred embodiment of an imaging lens 2 of the present invention includes a first lens element 3, an aperture stop 7, a second lens element 4, a third lens element 5, a fourth lens element 6, and an optical filter 8 arranged in the given order from an object side to an imaging side. Each of the first, second, third, and fourth lens elements 3, 4, 5, 6 is made of plastic, and has an object-side surface 31, 41, 51, 61 and an imaging-side surface 32, 42, 52, 62. The first and second lens elements 3, 4 have a gap with a width preferably not narrower than 0.08 mm formed therebetween. When light enters the imaging lens 2, it travels through the first lens element 3, the aperture stop 7, the second lens element 4, the third lens element 5, the fourth lens element 6, and the optical filter 8 in the given order, and eventually forms an image at an imaging plane 10 disposed at the imaging side.

The first lens element 3 is a biconvex lens element with a positive focusing power (i.e., a positive diopter or a positive refracting power). The second lens element 4 is a biconcave lens element with a negative focusing power, and has an abbe number not greater than 30. The third lens element 5 has a positive focusing power, and the object-side surface 51 and the imaging-side surface 52 thereof are a concave surface and a convex surface, respectively. The fourth lens element 6 has a negative focusing power, the object-side surface 61 thereof is a wavelike surface having a convex area 611 in a vicinity of an optical axis (I) of the fourth lens element 6, and the imaging-side surface 62 thereof is a wavelike surface having a concave area 621 in the vicinity of the optical axis (I) of the fourth lens element 6. The aperture stop 7 is disposed between the first and second lens elements 3, 4, and is disposed on the imaging-side surface 32 of the first lens element 3 in this embodiment. The optical filter 8 is a flat glass panel, and has an object-side surface 81 facing toward the object side, and an imaging-side surface 82 facing toward the imaging side and parallel to the object-side surface 81.

Table 1 shows optical parameters of the lens elements 3-6, the optical filter 8, and the imaging plane 10.

TABLE 1

| | Surface | Radius of Curvature (mm) | Thickness (mm) | Refractive Index | Abbe Number |
|----------------------|---------|--------------------------|----------------|------------------|-------------|
| First Lens element 3 | 31 | 1.142 | 0.300 | 1.544 | 56.12 |
| | 32 | -3.234 | 0.086 | | |

4

TABLE 1-continued

| | Surface | Radius of Curvature (mm) | Thickness (mm) | Refractive Index | Abbe Number |
|-----------------------|---------|--------------------------|----------------|------------------|-------------|
| Second lens element 4 | 41 | -6.872 | 0.200 | 1.607 | 27.00 |
| | 42 | 1.988 | 0.200 | | |
| Third Lens element 5 | 51 | -1.340 | 0.315 | 1.531 | 56.00 |
| | 52 | -0.633 | 0.080 | | |
| Fourth Lens element 6 | 61 | 0.933 | 0.300 | 1.531 | 56.00 |
| | 62 | 0.671 | 0.313 | | |
| Optical filter 8 | 81 | ∞ | 0.210 | 1.517 | 64.00 |
| | 82 | ∞ | 0.288 | | |
| Imaging plane 10 | — | ∞ | -0.004 | — | — |

The object-side surfaces 31, 41, 51, 61 and the imaging-side surfaces 32, 42, 52, 62 are aspherical surfaces, and may be defined by the following equation (1):

$$Z(X) = \frac{x^2/r}{1 + \sqrt{1 - (1 + K)\frac{x^2}{r^2}}} + AX^4 + BX^6 + CX^8 + DX^{10} + EX^{12} + FX^{14} \quad (1)$$

wherein (Z) represents an axis extending along the optical axis (I), (X) represents an axis extending perpendicular to the optical axis (I), and (r) is the radius of curvature (see Table 1). Moreover, Tables 2, 3 and 4 show conic constants (K), and higher-order aspherical surface coefficients (A), (B), (C), (D), (E), (F) of the object-side surfaces 31, 41, 51, 61 and the imaging-side surfaces 32, 42, 52, 62.

TABLE 2

| Surface | K | A | B |
|---------|-------------|-------------|-------------|
| 31 | -1.8593E+00 | 0.0000E+00 | 2.2558E-02 |
| 32 | 2.5855E+01 | 0.0000E+00 | 1.1308E+00 |
| 41 | 8.8402E+01 | 0.0000E+00 | 1.3501E+00 |
| 42 | 6.7216E+00 | 0.0000E+00 | 1.6877E-01 |
| 51 | 2.5264E+00 | 0.0000E+00 | -2.6674E-01 |
| 52 | -5.0546E-01 | 0.0000E+00 | -1.5400E-01 |
| 61 | 0.0000E+00 | -1.0100E+00 | 5.4318E-01 |
| 62 | -1.3578E+00 | -9.6118E-01 | 8.5293E-01 |

TABLE 3

| Surface | C | D | E |
|---------|-------------|------------|-------------|
| 31 | -1.1958E+00 | 0.0000E+00 | 0.0000E+00 |
| 32 | -7.3494E-01 | 0.0000E+00 | 0.0000E+00 |
| 41 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
| 42 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
| 51 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
| 52 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
| 61 | -1.2084E+00 | 2.6891E+00 | -2.1573E+00 |
| 62 | -5.9839E-01 | 4.0733E-01 | -3.0081E-01 |

TABLE 4

| Surface | F |
|---------|------------|
| 31 | 0.0000E+00 |
| 32 | 0.0000E+00 |
| 41 | 0.0000E+00 |
| 42 | 0.0000E+00 |
| 51 | 0.0000E+00 |

5

TABLE 4-continued

| Surface | F |
|---------|-------------|
| 52 | 0.0000E+00 |
| 61 | 0.0000E+00 |
| 62 | 0.069492928 |

Shown in FIG. 2 from left to right are plots of sagittal astigmatism (along a sagittal plane with respect to the imaging plane 10), tangential astigmatism (along a tangential plane with respect to the imaging plane 10), and distortion aberrations of the imaging lens 2 of the first preferred embodiment at three representative wavelengths (626 nm, 588 nm, and 486 nm). As shown in the plots of sagittal and tangential astigmatisms, the imaging lens 2 has a range of focal distances not exceeding ± 0.05 mm within the whole angle of view at each of the representative wavelengths. Furthermore, in each of the plots of sagittal and tangential astigmatisms, curves that respectively represent the three representative wavelengths are relatively similar, which indicates that the imaging lens 2 of the first preferred embodiment exhibits relatively low chromatic aberration. Moreover, the distortion aberrations that occur in the imaging lens 2 of the first preferred embodiment have a range within $\pm 0.3\%$. Therefore, the imaging lens 2 of the first preferred embodiment of the present invention has significant improvement over the prior art in terms of optical performance. FIG. 3 illustrates ray fan plots of the imaging lens 2 of the first preferred embodiment at normalized half-angles of view of 1, 0.8, and 0, which correspond to relative angles of view of 37.41°, 31.33°, and 0°, respectively. It is apparent that the imaging lens 2 is able to achieve low optical aberrations, and an angle of view of 74.82 degrees, which is wider than those generally achievable by conventional imaging lenses of the prior art.

Referring to FIG. 4, the second preferred embodiment of this invention has a configuration almost identical to that of the first preferred embodiment. The first lens element 3 is a biconvex lens element. The second lens element 4 is a biconcave lens element. The object-side surface 51 and the imaging-side surface 52 of the third lens element 5 are a concave surface and a convex surface, respectively. The object-side surface 61 of the fourth lens element 6 is a wavelike surface having a convex area 611 in the vicinity of the optical axis (I) of the fourth lens element 6, and the imaging-side surface 62 of the same is a wavelike surface having a concave area 621 in the vicinity of the optical axis (I) of the fourth lens element 6. The aperture stop 7 is disposed between the first and second lens elements 3, 4, and is disposed on the imaging-side surface 32 of the first lens element 3 in this invention.

Table 5 shows optical parameters of the lens elements 3-6, the optical filter 8, and the imaging plane 10 in the second preferred embodiment.

TABLE 5

| | Surface | Radius of Curvature (mm) | Thickness (mm) | Refractive Index | Abbe Number |
|-----------------------|---------|--------------------------|----------------|------------------|-------------|
| First Lens element 3 | 31 | 1.039 | 0.333 | 1.544 | 56.12 |
| | 32 | -21.301 | 0.167 | | |
| Second lens element 4 | 41 | -36.891 | 0.300 | 1.607 | 27.00 |
| | 42 | 1.328 | 0.191 | | |
| Third Lens element 5 | 51 | -3.560 | 0.573 | 1.531 | 56.00 |
| | 52 | -0.797 | 0.080 | | |
| Fourth Lens element 6 | 61 | 1.003 | 0.385 | 1.531 | 56.00 |
| | 62 | 0.680 | 0.313 | | |
| Optical | 81 | ∞ | 0.210 | 1.517 | 64.00 |

6

TABLE 5-continued

| | Surface | Radius of Curvature (mm) | Thickness (mm) | Refractive Index | Abbe Number |
|------------------|---------|--------------------------|----------------|------------------|-------------|
| filter 8 | 82 | ∞ | 0.218 | | |
| Imaging plane 10 | — | ∞ | -0.006 | — | — |

In the second preferred embodiment, the object-side surfaces 31, 41, 51, 61 and the imaging-side surfaces 32, 42, 52, 62 are aspherical surfaces and may be defined by the aforementioned equation (1). Tables 6 and 7 show conic constants (K), and higher-order aspherical surface coefficients (A), (B), (C), (D), (E) of the object-side surfaces 31, 41, 51, 61 and the imaging-side surfaces 32, 42, 52, 62. It is to be noted that, in this embodiment, the higher-order aspherical surface coefficient (F) of the object-side surfaces 31, 41, 51, 61 and the imaging-side surfaces 32, 42, 52, 62 has a value of "0", and hence is omitted from Tables 6 and 7.

TABLE 6

| Surface | K | A | B |
|---------|-------------|-------------|-------------|
| 31 | 1.2003E+00 | 0.0000E+00 | 7.7611E-02 |
| 32 | 0.0000E+00 | 3.0428E-01 | -3.7751E-01 |
| 41 | 0.0000E+00 | -1.3938E-01 | -1.2157E+00 |
| 42 | 1.8276E+00 | 0.0000E+00 | -1.0638E+00 |
| 51 | 0.0000E+00 | 2.5073E-01 | -1.4887E+00 |
| 52 | -1.3788E-02 | 0.0000E+00 | 1.1743E-01 |
| 61 | 0.0000E+00 | -9.3364E-01 | 4.8794E-01 |
| 62 | -9.0662E-01 | -1.0326E+00 | 8.2326E-01 |

TABLE 7

| Surface | C | D | E |
|---------|-------------|------------|-------------|
| 31 | -9.1967E-02 | 0.0000E+00 | 0.0000E+00 |
| 32 | 2.8013E-01 | 0.0000E+00 | 0.0000E+00 |
| 41 | -1.0664E+00 | 0.0000E+00 | 0.0000E+00 |
| 42 | 1.0191E+00 | 0.0000E+00 | 0.0000E+00 |
| 51 | 1.4743E+00 | 0.0000E+00 | 0.0000E+00 |
| 52 | -2.8925E-03 | 0.0000E+00 | 0.0000E+00 |
| 61 | -1.1042E+00 | 2.1865E+00 | -1.5911E+00 |
| 62 | -8.6586E-01 | 6.5005E-01 | -2.3789E-01 |

Shown in FIG. 5 from left to right are plots of sagittal astigmatism, tangential astigmatism, and distortion aberrations of the imaging lens 2 of the second preferred embodiment at the three representative wavelengths. As shown in the plots of sagittal and tangential astigmatisms, the imaging lens 2 has a range of focal distances not exceeding ± 0.05 mm within the whole angle of view at each of the representative wavelengths. Moreover, the distortion aberrations that occur in the imaging lens 2 of the second preferred embodiment have a range within ± 0.30 .

FIG. 6 illustrates ray fan plots of the imaging lens 2 of the second preferred embodiment at normalized half-angles of view of 1, 0.8, and 0, which correspond to relative angles of view of 33.00°, 27.58°, and 0°, respectively. It is apparent that the imaging lens 2 is able to achieve an angle of view of 66° and low optical aberrations.

Referring to FIG. 7, the third preferred embodiment of this invention has a configuration almost identical to that of the first preferred embodiment. The first lens element 3 is a biconvex lens element. The second lens element 4 is a biconcave lens element. The object-side surface 51 and the imaging-side surface 52 of the third lens element 5 are a concave surface

7

and a convex surface, respectively. The object-side surface **61** of the fourth lens element **6** is a wavelike surface having a convex area **611** in the vicinity of the optical axis (I) of the fourth lens element **6**, and the imaging-side surface **62** of the same is a wavelike surface having a concave area **621** in the vicinity of the optical axis (I) of the fourth lens element **6**. The aperture stop **7** is disposed between the first and second lens elements **3**, **4**, and is disposed on the imaging-side surface **32** of the first lens element **3** of this invention.

Table 8 shows optical parameters of the lens elements **3-6**, the optical filter **8**, and the imaging plane **10** in the third preferred embodiment.

TABLE 8

| | Surface | Radius of Curvature (mm) | Thickness (mm) | Refractive Index | Abbe Number |
|-----------------------|---------|--------------------------|----------------|------------------|-------------|
| First Lens element 3 | 31 | 1.065 | 0.332 | 1.531 | 56.00 |
| | 32 | -30.651 | 0.200 | | |
| Second lens element 4 | 41 | -30.653 | 0.3000 | 1.607 | 27.00 |
| | 42 | 1.217 | 0.1535 | | |
| Third Lens element 5 | 51 | -673.972 | 0.697 | 1.531 | 56.00 |
| | 52 | -0.697 | 0.080 | | |
| Fourth Lens element 6 | 61 | 1.450 | 0.418 | 1.531 | 56.00 |
| | 62 | 0.648 | 0.313 | | |
| Optical filter 8 | 81 | ∞ | 0.210 | 1.517 | 64.00 |
| | 82 | ∞ | 0.167 | | |
| Imaging plane 10 | — | ∞ | -0.001 | — | — |

In the third preferred embodiment, the object-side surfaces **31**, **41**, **51**, **61** and the imaging-side surfaces **32**, **42**, **52**, **62** are aspherical surfaces and may be defined by the aforementioned equation (1). Tables 9 and 10 show conic constants (K), and higher-order aspherical surface coefficients (A), (B), (C), (D), (E) of the object-side surfaces **31**, **41**, **51**, **61** and the imaging-side surfaces **32**, **42**, **52**, **62**. It is to be noted that, in this embodiment, the higher-order aspherical surface coefficient (F) of each of the object-side surfaces **31**, **41**, **51**, **61** and the imaging-side surfaces **32**, **42**, **52**, **62** has a value of "0", and hence is omitted from Tables 9 and 10.

TABLE 9

| Surface | K | A | B |
|---------|-------------|-------------|-------------|
| 31 | 1.5909E+00 | 0.0000E+00 | 5.5339E-02 |
| 32 | 0.0000E+00 | 3.3553E-01 | -3.2334E-01 |
| 41 | 0.0000E+00 | -2.9897E-01 | -7.5085E-01 |
| 42 | -8.3854E-01 | 0.0000E+00 | -6.2382E-01 |
| 51 | 0.0000E+00 | 7.4113E-02 | -6.7356E-01 |
| 52 | -3.9205E-01 | 0.0000E+00 | 3.5454E-01 |
| 61 | 0.0000E+00 | -1.0339E+00 | 8.4838E-01 |
| 62 | -1.2092E+00 | -1.2526E+00 | 1.4408E+00 |

TABLE 10

| Surface | C | D | E |
|---------|-------------|------------|-------------|
| 31 | -1.2377E-01 | 0.0000E+00 | 0.0000E+00 |
| 32 | 7.1020E-01 | 0.0000E+00 | 0.0000E+00 |
| 41 | -3.6288E+00 | 0.0000E+00 | 0.0000E+00 |
| 42 | 6.5857E-01 | 0.0000E+00 | 0.0000E+00 |
| 51 | 1.1019E+00 | 0.0000E+00 | 0.0000E+00 |
| 52 | -3.9701E-01 | 0.0000E+00 | 0.0000E+00 |
| 61 | -5.9630E-01 | 1.0278E+00 | -1.0836E+00 |
| 62 | 1.2621E+00 | 6.2777E-01 | -1.6493E-01 |

Shown in FIG. 8 from left to right are plots of sagittal astigmatism, tangential astigmatism, and distortion aberrations of the imaging lens **2** of the third preferred embodiment at the three representative wavelengths. FIG. 9 illustrates ray fan plots of the imaging lens **2** of the third preferred embodiment at normalized half-angles of view of 1, 0.8, and 0, which correspond to relative angles of view of 33.00°, 27.51°, and 0°, respectively. It is apparent that the imaging lens **2** is able to achieve an angle of view of 66° and low optical aberrations.

8

Referring to FIG. 10, the fourth preferred embodiment of this invention has a configuration almost identical to that of the first preferred embodiment. The first lens element **3** is a biconvex lens element. The second lens element **4** is a biconcave lens element. The object-side surface **51** and the imaging-side surface **52** of the third lens element **5** are a concave surface and a convex surface, respectively. The object-side surface **61** of the fourth lens element **6** is a wavelike surface having a convex area **611** in the vicinity of the optical axis (I) of the fourth lens element **6**, and the imaging-side surface **62** of the same is a wavelike surface having a concave area **621** in the vicinity of the optical axis (I) of the fourth lens element **6**. The aperture stop **7** is disposed between the first and second lens elements **3**, **4**, and is disposed on the imaging-side surface **32** of the first lens element **3** in this embodiment.

Table 11 shows optical parameters of the lens elements **3-6**, the optical filter **8**, and the imaging plane **10** in the fourth preferred embodiment.

TABLE 11

| | Surface | Radius of Curvature (mm) | Thickness (mm) | Refractive Index | Abbe Number |
|-----------------------|---------|--------------------------|----------------|------------------|-------------|
| First Lens element 3 | 31 | 0.942 | 0.357 | 1.544 | 56.12 |
| | 32 | -5.700 | 0.107 | | |
| Second lens element 4 | 41 | -16.250 | 0.300 | 1.607 | 27.00 |
| | 42 | 1.129 | 0.188 | | |
| Third Lens element 5 | 51 | -18.518 | 0.525 | 1.531 | 56.00 |
| | 52 | -1.076 | 0.080 | | |
| Fourth Lens element 6 | 61 | 0.972 | 0.310 | 1.531 | 56.00 |
| | 62 | 0.723 | 0.313 | | |
| Optical filter 8 | 81 | ∞ | 0.210 | 1.517 | 64.00 |
| | 82 | ∞ | 0.185 | | |
| Imaging plane 10 | — | ∞ | -0.022 | — | — |

In the fourth preferred embodiment, the object-side surfaces **31**, **41**, **51**, **61** and the imaging-side surfaces **32**, **42**, **52**, **62** are aspherical surfaces and may be defined by the aforementioned equation (1). Tables 12 and 13 show conic constants (K), and higher-order aspherical surface coefficients (A), (B), (C), (D), (E) of the object-side surfaces **31**, **41**, **51**, **61** and the imaging-side surfaces **32**, **42**, **52**, **62**. It is to be noted that, in this embodiment, the higher-order aspherical surface coefficient (F) of each of the object-side surfaces **31**, **41**, **51**, **61** and the imaging-side surfaces **32**, **42**, **52**, **62** has a value of "0", and hence is omitted from Tables 12 and 13.

TABLE 12

| Surface | K | A | B |
|---------|-------------|-------------|-------------|
| 31 | 6.6012E-01 | 0.0000E+00 | -4.1214E-02 |
| 32 | 0.0000E+00 | 4.6103E-01 | -5.0339E-01 |
| 41 | 0.0000E+00 | 1.9266E-01 | -1.5847E+00 |
| 42 | 1.7393E+00 | 0.0000E+00 | -1.2067E+00 |
| 51 | 0.0000E+00 | 5.0072E-01 | -2.9983E+00 |
| 52 | 3.4241E-02 | 0.0000E+00 | -4.5071E-01 |
| 61 | 0.0000E+00 | -1.1828E+00 | 4.6896E-01 |
| 62 | -1.4151E+00 | -1.1188E+00 | 1.1673E+00 |

TABLE 13

| Surface | C | D | E |
|---------|-------------|------------|-------------|
| 31 | 6.4481E-01 | 0.0000E+00 | 0.0000E+00 |
| 32 | -1.6260E-01 | 0.0000E+00 | 0.0000E+00 |
| 41 | -2.2720E-01 | 0.0000E+00 | 0.0000E+00 |
| 42 | 1.1741E+00 | 0.0000E+00 | 0.0000E+00 |
| 51 | 3.6965E+00 | 0.0000E+00 | 0.0000E+00 |
| 52 | -3.1569E-02 | 0.0000E+00 | 0.0000E+00 |
| 61 | -1.0668E+00 | 2.0910E+00 | -1.4669E+00 |
| 62 | -1.0752E+00 | 5.9753E-01 | -1.8835E-01 |

Shown in FIG. 11 from left to right are plots of sagittal astigmatism, tangential astigmatism, and distortion aberrations of the imaging lens 2 of the fourth preferred embodiment at the three representative wavelengths. FIG. 12 illustrates ray fan plots of the imaging lens 2 of the fourth preferred embodiment at normalized half-angles of view of 1, 0.8, and 0, which correspond to relative angles of view of 33.00°, 27.51°, and 0°, respectively. It is apparent that the imaging lens 2 is able to achieve an angle of view of 66° and low optical aberrations.

Table 14 shows optical parameters of the preferred embodiments for comparison.

TABLE 14

| Imaging Height = 1.2 mm | | | | |
|-------------------------|----------------------|---------|---------|--------|
| | Preferred Embodiment | | | |
| | 1 | 2 | 3 | 4 |
| F Number | 2.4 | 2.4 | 2.4 | 2.4 |
| Half-angle of view | 37.4 | 33.0 | 33.0 | 33.0 |
| f | 1.575 | 1.845 | 1.851 | 1.859 |
| TL | 2.288 | 2.764 | 2.868 | 2.553 |
| f1 | 1.598 | 1.841 | 1.955 | 1.522 |
| f2 | -2.544 | -2.127 | -1.941 | -1.745 |
| f3 | 1.966 | 1.183 | 1.320 | 2.140 |
| f4 | -7.457 | -6.806 | -2.704 | -9.374 |
| f12 | 3.187 | 4.656 | 6.584 | 3.753 |
| R21/f | -4.363 | -19.999 | -16.557 | -8.741 |
| R12/R21 | 0.471 | 0.577 | 1.000 | 0.351 |
| Wg | 0.086 | 0.167 | 0.200 | 0.107 |
| f1/f | 1.014 | 0.998 | 1.056 | 0.819 |
| TL/f | 1.453 | 1.498 | 1.549 | 1.373 |
| f12/f | 2.023 | 2.524 | 3.556 | 2.019 |

It is to be noted that the F number represents a ratio between a focal length of the imaging lens 2 and a diameter of an entrance pupil of the aperture stop 7, and W_g represents the width of the gap between the first and second lens elements 3, 4.

The imaging lens 2 of each of the preferred embodiments satisfies optical conditions 2 to 6, which are described hereinafter.

Optical condition 2:

$$-21 \leq R_{21}/f < 0 \quad (2)$$

wherein R_{21} represents a radius of curvature of the object-side surface 41 of the second lens element 4, and f represents the focal length of the imaging lens 2. The imaging lens 2 must satisfy optical condition 2 such that chromatic aberrations may be significantly reduced and stronger bonding between the imaging-side surface 32 of the first lens element 3 and the object-side surface 41 of the second lens element 4 may be ensured.

Optical condition 3:

$$R_{12}/R_{21} \leq 1.1 \quad (3)$$

wherein R_{12} represents a radius of curvature of the imaging-side surface 32 of the first lens element 1. The imaging lens 2 must satisfy optical condition 3, and the gap between the first and second lens elements 3, 4 must have a width not narrower than 0.08 mm, so as to alleviate peripheral interference between the first and second lens elements 3, 4, which may influence the structural integrity of the imaging lens 2.

Optical condition 4:

$$0.7 < f_1/f \leq 1.1 \quad (4)$$

wherein f_1 represents a focal length of the first lens element 3.

If the value of f_1/f is greater than 1.1, the positive focusing power of the first lens element 3 will be too low and must be compensated for by the other lens elements 4-6, which, as a consequence, will increase the overall length of the imaging lens 2. On the other hand, if the value of f_1/f is not greater than 0.7, the positive focusing power of the first lens element 3 will be too high, causing the first lens element 3 to exhibit severe distortion aberration. Although the other lens element 4-6 may be configured to compensate for the low positive focusing power of the first lens element 3, the effect of which is rather limited since design of the imaging lens 2 is substantially based upon the first lens element 3.

Optical condition 5:

$$TL/f < 1.55 \quad (5)$$

wherein TL represents a distance between the object-side surface 31 of the first lens element 3 and the imaging plane 10. If the imaging lens 2 fails to satisfy optical condition 5, the overall length thereof will be too long, rendering it less applicable to miniaturized products.

Optical condition 6:

$$1 < f_{12}/f < 4.5 \quad (6)$$

wherein f_{12} represents a combined focal length of the first and second lens elements 3, 4.

If the value of f_{12}/f is not smaller than 4.5, the combined focal length of the first and second lens elements 3, 4 will be too long. That is to say, a combined positive focusing power of the first and second lens elements 3, 4 will be too low. Further, compensation by the other lens elements 5-6 will be insufficient to shorten the combined focal length significantly. If the value of f_{12}/f is not larger than 1, the combined focal length of the first and second lens elements 3, 4 will be too short. That is to say, the combined positive focusing power of the first and second lens elements 3, 4 will be too high. As a result, the first and second lens elements 3, 4 in combination will exhibit high distortion aberration. Moreover, the effect of compensation by the other lens elements 5-6 will be rather limited.

Referring to FIG. 13, the preferred embodiment of an electronic apparatus 1 according to this invention includes a housing 11 and an imaging module 12 disposed in the housing 11. In this embodiment, the electronic apparatus 1 is exemplified as a mobile phone. However, in other embodiments, the electronic apparatus 1 may be implemented otherwise. The imaging module 12 includes the imaging lens 2 of the first preferred embodiment, and an image sensor 121 disposed at the imaging plane 10.

In summary, the imaging lenses 2 of the preferred embodiments have relatively low sagittal and tangential astigmatisms, distortion aberrations, and chromatic aberrations, and have a relatively wide angle of view.

Furthermore, the first, second, third, and fourth lens elements 3-6 are made of plastic and hence have low weights and may be fabricated at lower costs.

11

While the present invention has been described in connection with what are considered the most practical and preferred embodiments, it is understood that this invention is not limited to the disclosed embodiments but is intended to cover various arrangements included within the spirit and scope of the broadest interpretation so as to encompass all such modifications and equivalent arrangements.

What is claimed is:

1. An optical imaging lens comprising a plurality of lens elements, each of the plurality of lens elements having a refracting power, an object-side surface facing toward the object-side, and an imaging-side surface facing toward the imaging-side, the plurality of lens elements comprising:

a first lens element closest to the object-side;

a second lens element second closest to the object-side, wherein the second lens element has a negative refracting power and the imaging-side surface of the second lens element comprises a concave surface;

a third lens element third closest to the object-side, wherein the third lens element has a positive refracting power, the object-side surface of the third lens element comprises a concave surface, and the imaging-side surface of the third lens element comprises a convex surface; and

a fourth lens element closest to the imaging-side, wherein the object-side surface of the fourth lens element comprises a convex area in a vicinity of the optical axis and the imaging-side surface of the fourth lens element comprises a concave area in a vicinity of the optical axis,

wherein a thickness of the first lens element at the optical axis is defined as T1, a thickness of the second lens element at the optical axis is defined as T2, a thickness of the third lens element at the optical axis is defined as T3, a thickness of the fourth lens element at the optical axis is defined as T4, an air gap between the first lens element and the second lens element at the optical axis is defined as AG12, an air gap between the second lens element and the third lens element at the optical axis is defined as AG23, and T1, T2, T3, T4, AG12 and AG23 satisfy the relations:

$$0.74 \leq (T1+T2)/(T3+AG23) \leq 0.97;$$

$$3.16 \leq (T1+T2)/AG12 \leq 6.14; \text{ and}$$

$$3.00 \leq (T1+T4)/AG23 \leq 4.89.$$

2. The optical imaging lens of claim 1 wherein a sum of (T1+T4) and AG23 satisfy the relation:

$$3.76 \leq (T1+T4)/AG23.$$

12

3. The optical imaging lens of claim 1 wherein the first lens element has a positive refracting power.

4. The optical imaging lens of claim 1 wherein the object-side surface of the first lens element comprises a convex surface.

5. The optical imaging lens of claim 1 wherein T1 and AG12 satisfy the relation:

$$1.66 \leq T1/AG12 \leq 3.49.$$

6. The optical imaging lens of claim 5 wherein AG12 and T2 satisfy the relation:

$$0.36 \leq AG12/T2 \leq 0.67.$$

7. The optical imaging lens of claim 6 wherein T2 and T3 satisfy the relation:

$$0.43 \leq T2/T3 \leq 0.63.$$

8. The optical imaging lens of claim 1 wherein a sum of (T2+T3+AG23) and AG12 satisfy the relation:

$$5.75 \leq (T2+T3+AG23)/AG12 \leq 9.47.$$

9. The optical imaging lens of claim 8 wherein T3 and T2 satisfy the relation:

$$1.58 \leq T3/T2 \leq 2.32.$$

10. The optical imaging lens of claim 9 wherein T2 and AG12 satisfy the relation:

$$1.50 \leq T2/AG12 \leq 2.80.$$

11. The optical imaging lens of claim 1 wherein a sum of (T1+T2) and AG12 satisfy the relation:

$$3.79 \leq (T1+T2)/AG12.$$

12. The optical imaging lens of claim 11 wherein a sum of (T1+T2) and AG12 satisfy the relation:

$$(T1+T2)/AG12 \leq 5.81.$$

13. The optical imaging lens of claim 1 wherein a sum of (T1+T2) and (T3+AG23) satisfy the relation:

$$0.83 \leq (T1+T2)/(T3+AG23).$$

14. The optical imaging lens of claim 13 wherein a sum of (T1+T2) and (T3+AG23) satisfy the relation:

$$(T1+T2)/(T3+AG23) \leq 0.92.$$

* * * * *